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Gamma-ray Observation of the Cygnus Region with the Tibet Air Shower Array

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for the Tibet ASγ Collaboration

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We report detections of 2 gamma-ray sources with energies above 10 TeV from the Cygnus region.

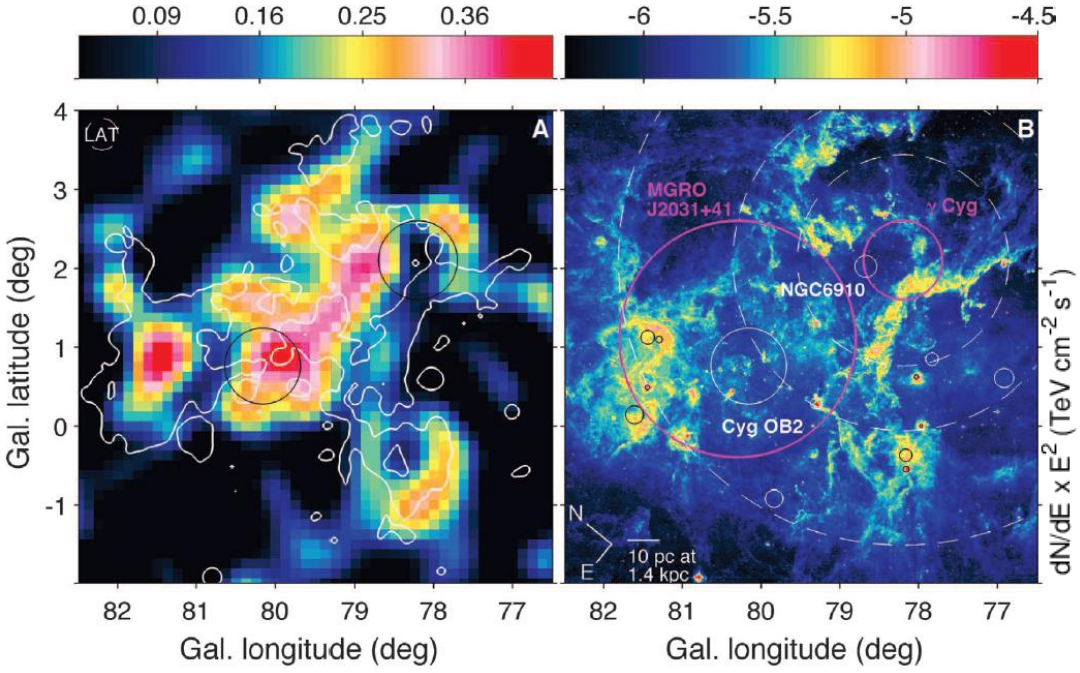
TASG J2032+414 in Cygnus OB2
and
TASG J2019+368 in Cygnus OB1.

Contents

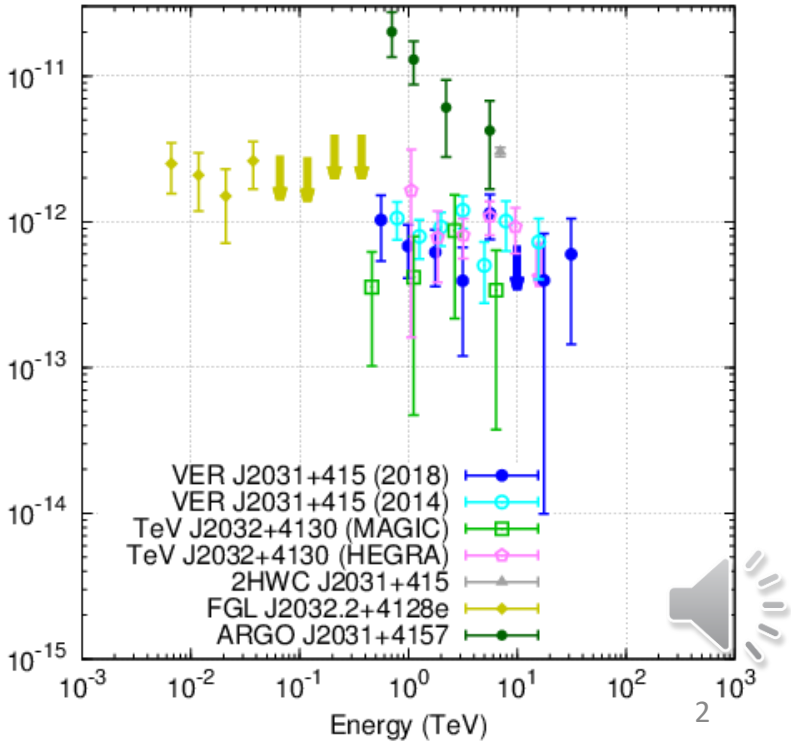
Introduction
- TeV gamma ray observation of the Cygnus region -

Cygnus region :star-forming region , natural laboratory
to study cosmic ray acceleration and transport.

Cygnus OB2 : Photon count residual map
in the 10 to 100 GeV band of the Fermi -LAT



Gamma ray spectrum
around Cygnus OB2



A Cocoon of Freshly Accelerated Cosmic Rays Detected by Fermi in the Cygnus Superbubble M. Ackermann *et al.*, Science **334**, 1103 (2011).

The Tibet ASg Collaboration

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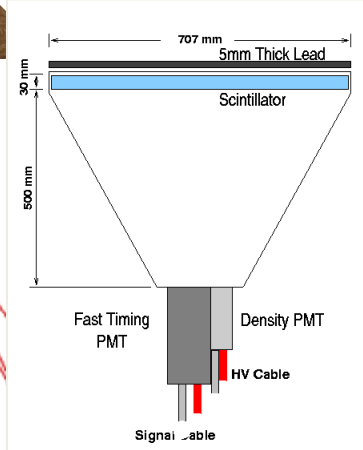
Tibet-III Air Shower Array

- Tibet, China (90.522°E, 30.102°N) 4,300 m a.s.l.

scintillation counters	0.5 m^2 x 597
area	~65,700 m^2
angular resolution	~0.5° @10TeV
	~0.2° @100TeV
energy resolution	~40% @10TeV
	~20% @100TeV

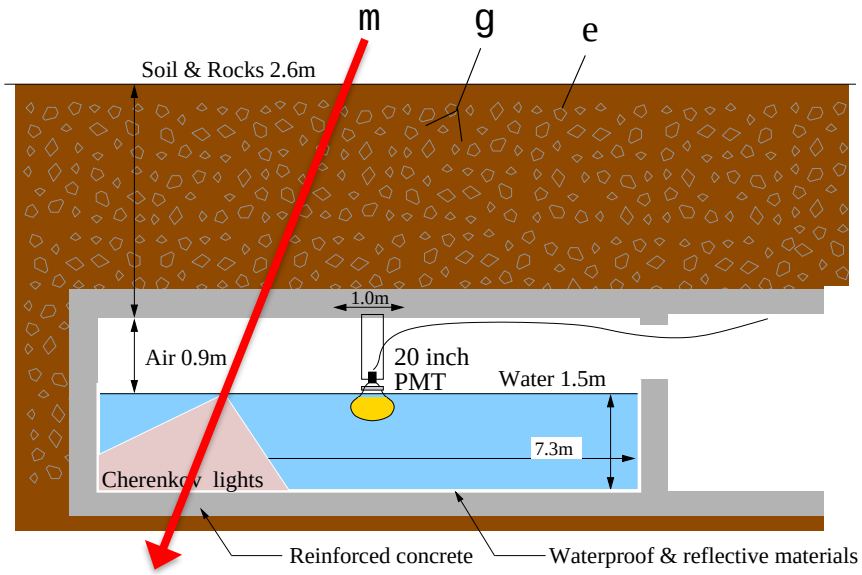
2nd particles timing ➡ arrival direction

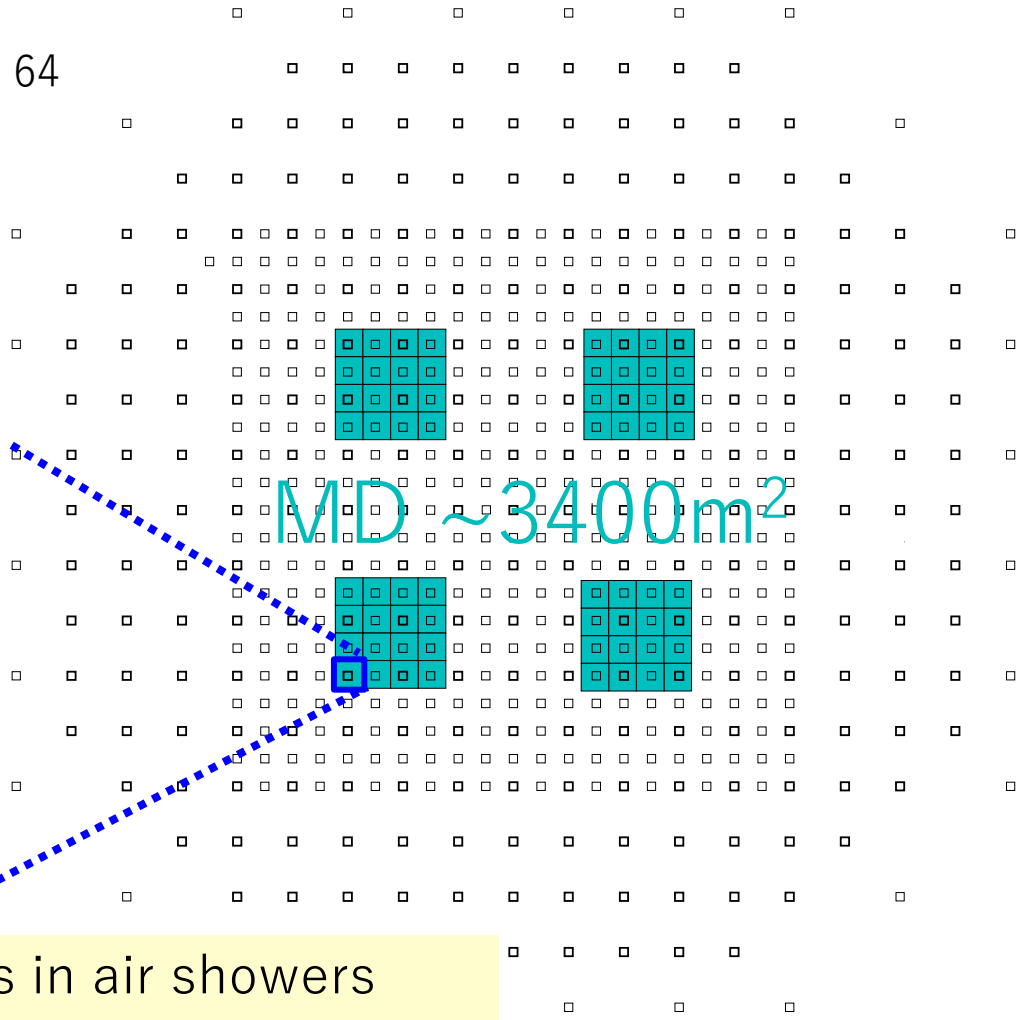
2nd particles energy deposit ➡ primary energy



Water Cherenkov Muon Detector Array

- ✓ 2.4m underground (515g/cm^2 ~19X_0)
- ✓ 7.35m x 7.35m x 1.5m-deep water cell x 64
- ✓ 20”ΦPMT (HAMAMATSU R3600)
- ✓ Concrete pools + Tyvek sheets



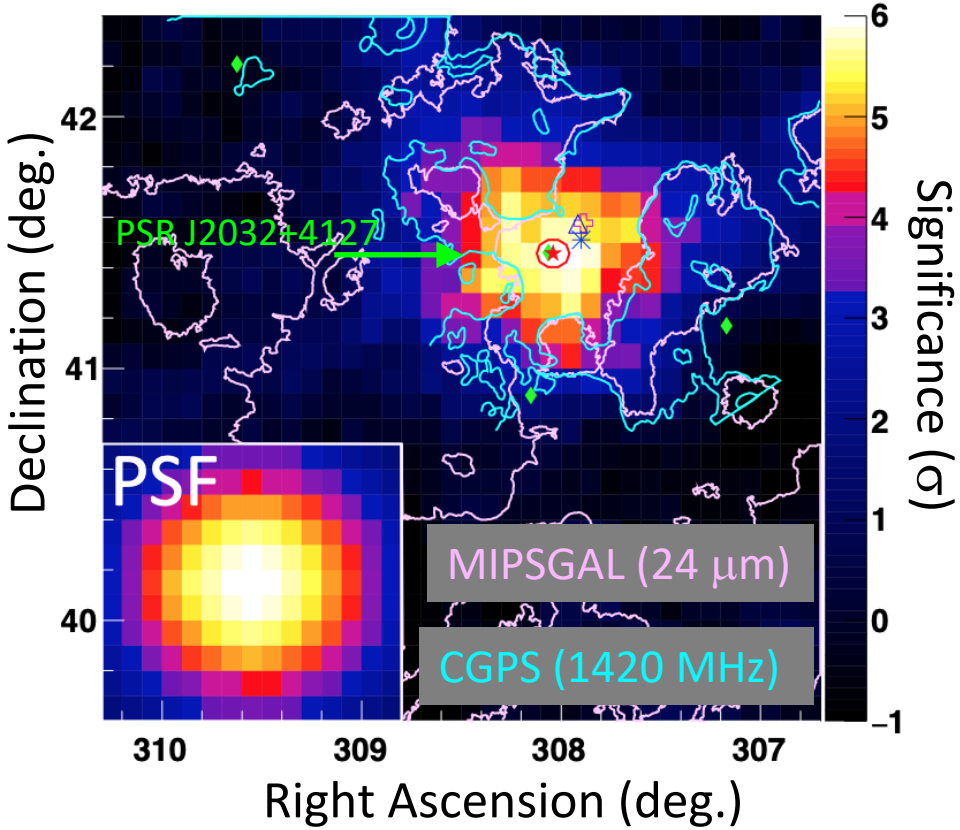


Measurement of number of muons in air showers
➡ γ／CR discrimination

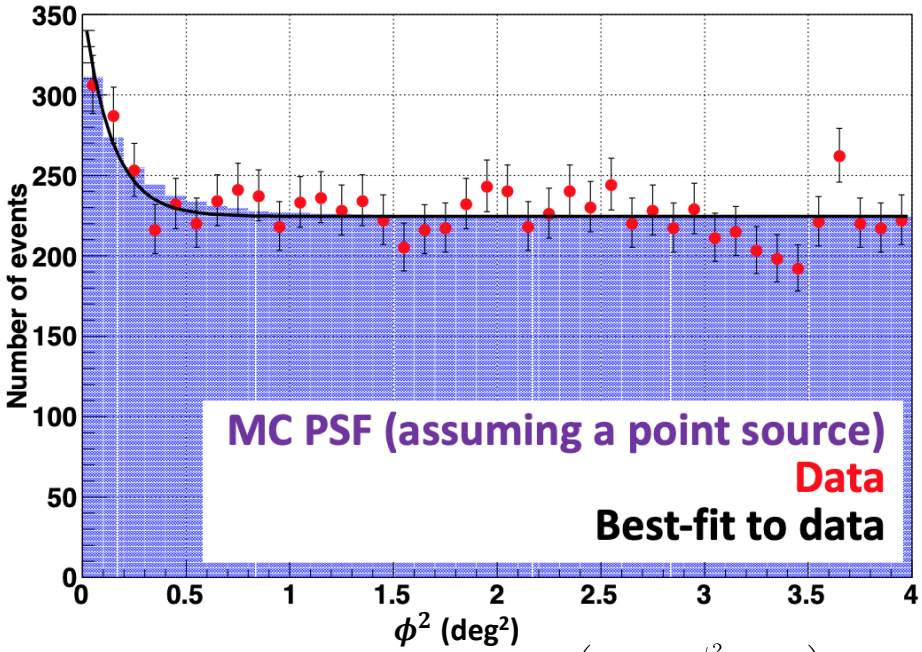
Data: 719 live days from 2014 February to 2017 May

TASG J2032+414 (Cygnus OB2)

Significance map > 10 TeV



Angular distribution > 10 TeV



Fitting with Gaussian:

σ_{PSF} = 0.36° from MC simulation

σ_{EXT}: source extension

➡ **$\sigma_{EXT} = 0.00° \pm 0.14°$**

Consistent with σ_{EXT} = 0.2°

★ **this work**

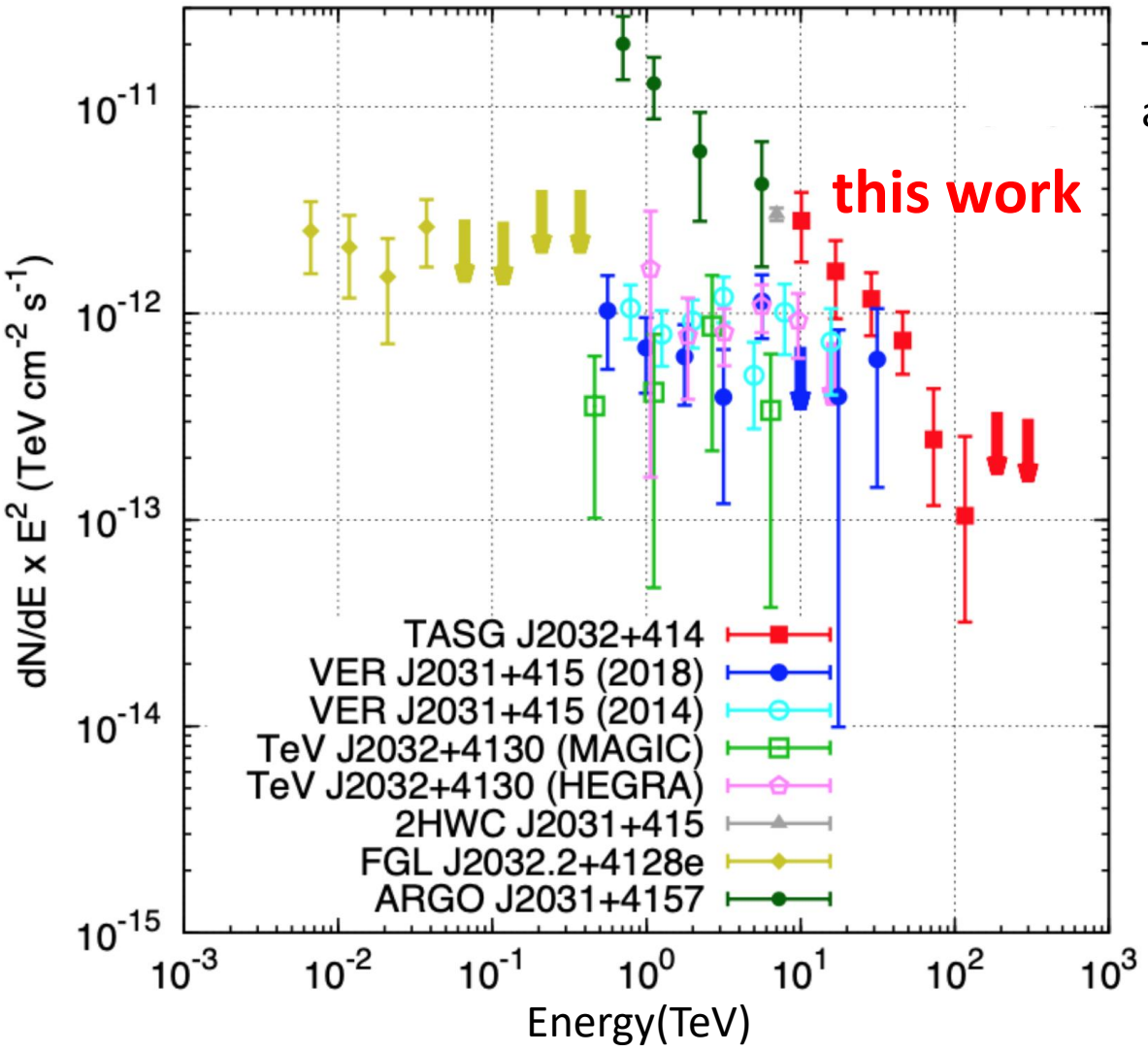
♦ Fermi ✚ VERITAS ✱ HAWC △ MAGIC

- Detection significance 5.3σ > 10 TeV
- Source position coincident with PSR J2032+4127

Abeysekara+, ApJL, 867, L19 (2018)
Abeysekara+, Nat. Astron. Let. (2021)
Abdollahi+, ApJ, Suppl. Ser., 247, 33 (2020)
Taylor+, Astron. J. 125, 3145 (2003)
Beerer+, ApJ, 720, 679 (2010)
Kraemer+, Astron. J., 139, 2319 (2010)

TASG J2032+414 (Cygnus OB2)

γ-ray energy spectrum



This work can be fitted by a simple power law:

$$\frac{dF}{dE} = N_0 \left(\frac{E}{40\ \mathrm{TeV}} \right)^{-\Gamma}$$

$$N_0 = (4.13 \pm 0.83) \times 10^{-16}\ \mathrm{TeV}^{-1}\mathrm{cm}^{-2}\mathrm{s}^{-1}$$

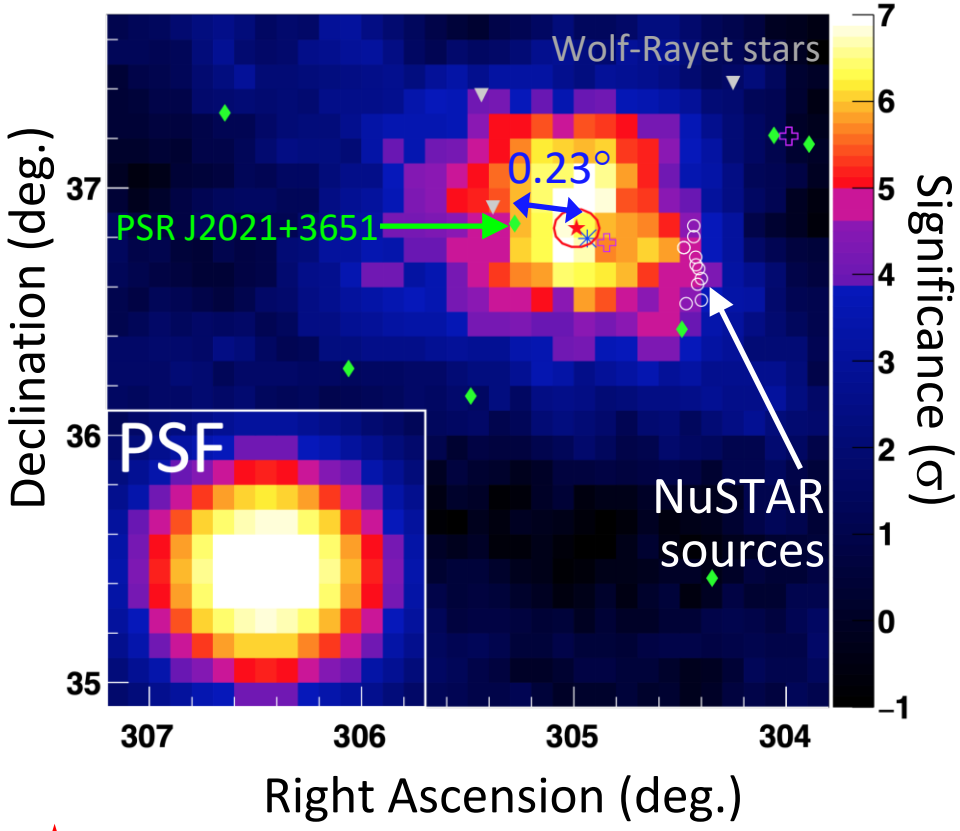
$$\Gamma = 3.12 \pm 0.21 \qquad (\chi^2/\mathrm{ndf} = 1.6/4)$$

Gamma rays likely produced via IC scattering by electrons produced by PSR J2021+3651

Abeysekara+, ApJ, 861, 134 (2018)
Aliu+, ApJ, 783, 16 (2014)
Albert+, ApJL, 675, L25 (2008)
Aharonian+, A&A, 431, 197 (2005)
Abeysekara+, Nat. Astron. Let. (2021)
Bartoli+, ApJL, 745, L22 (2012)

TASG J2019+368 (Cygnus OB1)

Significance map > 10 TeV

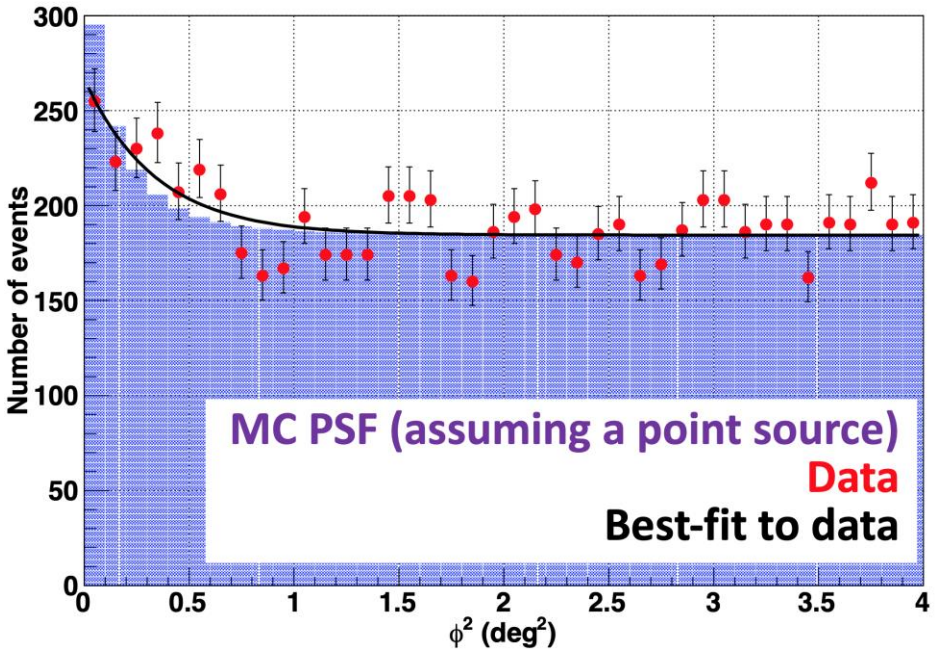


★ **this work**

♦ Fermi ✚ VERITAS ✱ HAWC

- Detection significance 6.7σ > 10 TeV
- Source position coincident with PWN G75.2+0.1
  0.23° west of PSR J2021+3651

Angular distribution > 10 TeV



Fitting with Gaussian: $A \exp\left(-\frac{\phi^2}{2(\sigma_{\rm PSF}^2+\sigma_{\rm EXT}^2)}\right)$

σ_{PSF} = 0.30° from MC simulation

σ_{EXT}: source extension

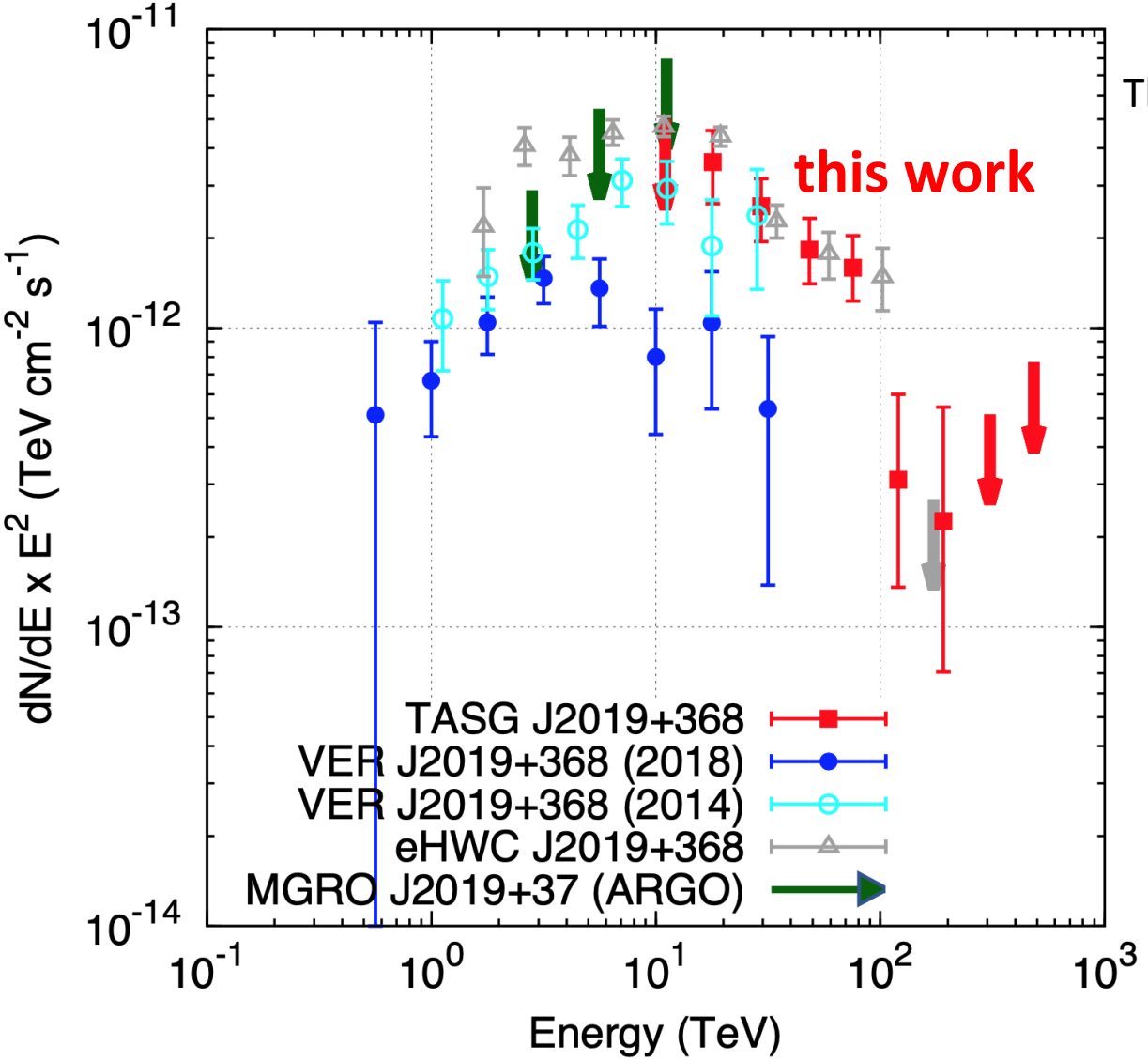
➡ **σ_{EXT} = 0.28° ± 0.07°**

Consistent with Veritas/HAWC

Abdollahi+, ApJ, Suppl. Ser., 247, 33 (2020)
Van der Hucht, New Astron. Rev. 45, 135 (2001)
Abeysekara+, ApJ, 861, 134 (2018)
Albert+, ApJ, 905, 76 (2020)
Gotthelf+, ApJ, 826, 25 (2016)

TASG J2019+368 (Cygnus OB1)

γ-ray energy spectrum



This work can be fitted by

$$\frac{dF}{dE} = N_0 \left(\frac{E}{40\ \mathrm{TeV}}\right)^{-\Gamma} \exp\left(-\frac{E}{E_{\mathrm{cut}}}\right)$$

$$N_0 = (3.6 \pm 2.0) \times 10^{-15}\ \mathrm{TeV}^{-1}\mathrm{cm}^{-2}\mathrm{s}^{-1}$$

$$\Gamma = 1.6 \pm 0.5$$

$$E_{\mathrm{cut}} = 44 \pm 21\ \mathrm{TeV} \quad (\chi^2/\mathrm{ndf} = 3.0/4)$$

Summary

Gamma ray observation of Cygnus was performed with the Tibet air shower array

719 live days from 2014 February to 2017 May

2 gamma-ray sources were detected.

- TASG J2032+414 (Cygnus OB2)
  - (R.A., Dec.) = $(308.04° \pm 0.08°, 41.46° \pm 0.06°)$, coincident with PSR J2032+4127.
  - Gamma ray spectrum from 10 TeV to 120 TeV

$$\frac{dF}{dE} = N_0 \left(\frac{E}{40\ \mathrm{TeV}}\right)^{-\Gamma} \qquad N_0 = (4.13 \pm 0.83) \times 10^{-16}\ \mathrm{TeV}^{-1}\mathrm{cm}^{-2}\mathrm{s}^{-1} \qquad \Gamma = 3.12 \pm 0.21$$

- TASG J2019+368 (Cygnus OB1)
  - (R.A., Dec.) = $(304.99° \pm 0.11°, 36.84° \pm 0.08°)$, coincident with PWN G75.2+0.1.
  - Gamma ray spectrum from 10 TeV to 200 TeV

$$\frac{dF}{dE} = N_0 \left(\frac{E}{40\ \mathrm{TeV}}\right)^{-\Gamma} \exp\left(-\frac{E}{E_{\mathrm{cut}}}\right) \qquad N_0 = (3.6 \pm 2.0) \times 10^{-15}\ \mathrm{TeV}^{-1}\mathrm{cm}^{-2}\mathrm{s}^{-1} \qquad \Gamma = 1.6 \pm 0.5$$

$$E_{\mathrm{cut}} = 44 \pm 21\ \mathrm{TeV}$$

END